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Functional Relationships Between Benthic Animals and Their Habitats in Tidal Flat

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Summary

The present investigation was designed to elucidate biological production mechanism of macro benthic animals such as bivalves and crabs in tidal flat communities and intended to provide some basic information for the relationships among several sub-ecosystems geographically specialized in estuary.

In order to investigate the trophic life of benthic animals and conditions of their habitat, the research work was performed in the mouth of the Natori River in Miyagi Prefecture from 1993 to 1995. The samples were collected by the quadrat method, and surveyed environmental factors, such as grain size, silt-clay content and the moisture of the bottm sediments, in each station. On the other hand, to make clear the feeding behavior of the animals, food items in the stomach of animals and the distribution of diatoms and detritus on the surface of tidal flat were precisely observed.

Four species of bivalves and five species of crabs inhabit dominantly in the tidal flat, forming patches parallel to the gradient of habitat conditions. In the case of *Nuttalia olivacea*, in accordance with growth, they vertically select different microhabitat, and they select a particular habitat in preference to others. These phenomena reveal that no two benthic species in the same general habitat can occupy for long identically the same position, that is to say, there are several different biological production processes spatially specialized in tidal flat subsystem.

However, it is recognized that functional continuity as to nutritional circulation is maintained among different micro-subsystems. These nutritional materials for the production of benthic microalgae are mainly transported by tidal current and secondary produced materials are transferred by movement of benthic animals.

From the results mentioned above, we can appreciate the estuary ecosystem constructed by different subsystems are basically linked through cooperation with biotic and abiotic components in the system.

The brackish water ecosystem is constituted with several subsystems such as estuary, river and coastal regions, which are geologically specialized. And it is considered that each subsystem is composed of several micro-subsystems caracterized by different environmental conditions and community structure. It is supposed that these subsystems would be coupled by the water current and the movement of organisms.

Many reports of ecological studies on the relationships between benthos and environments in the estuary have been described concerning the distribution of benthic animals (1, 3, 4). However, there is not many study on the continuity among subsystems.

The ultimate purpose of this study is to make clear the coupling mechanism among subsystems in the estuary ecosystem. The authors studied mainly the functional relationships between benthic animals and their habitat conditions. The most important thing is to know the functional relationships between the organisms and the environment, and the role playing in the ecosystem.

This paper describes the way of life among benthic animals in the field, as well as the physical conditions such as grain size, silt-clay content and moisture. From the results of field observation, we may conclude that there is species specific combination of environmental elements represented by the pattern of radar chart. We discuss the coupling mechanism in consequence of nutrient circulation among neighboring micro habitats in the estuary.

Materials and Methods

The survey and observation were carried out at tidal flats in the Mouth of the Natori River and the Hiroura from 1993 to 1995 (Fig. 1). The width and length of the tidal flats in the Natori river and in the Hiroura are 80×100 m, and $100 \times 1{,}000$ m, respectively.

Physicochemical survey

The relative levels were measured to know the ups and downs of the tidal flat in the Natori River. The way of inflow and outflow of the tidal current was observed and exposure periods of flat were measured on Spring Tide and Neap Tide. To elucidate the gradient of sediment type and the distribution of benthic animals in the tidal flat, 5 stations and 3 stations were decided along Line A and B respectively, as shown in Fig. 2.

In order to detect sediment characteristics, bottom sediments were collected by use of core sampler, diameter in 5 cm and length in 20 cm, every three month and analyzed on grain size, silt-clay contents, moisture, sediment-chlorophyll *a* and COD.

As to river water, water temperature was measured, and the samples were collected at ebb time every month, and they were analyzed for salinity, dissolved total nitrogen, dissolved total phosphorous and chrolophyll *a*.

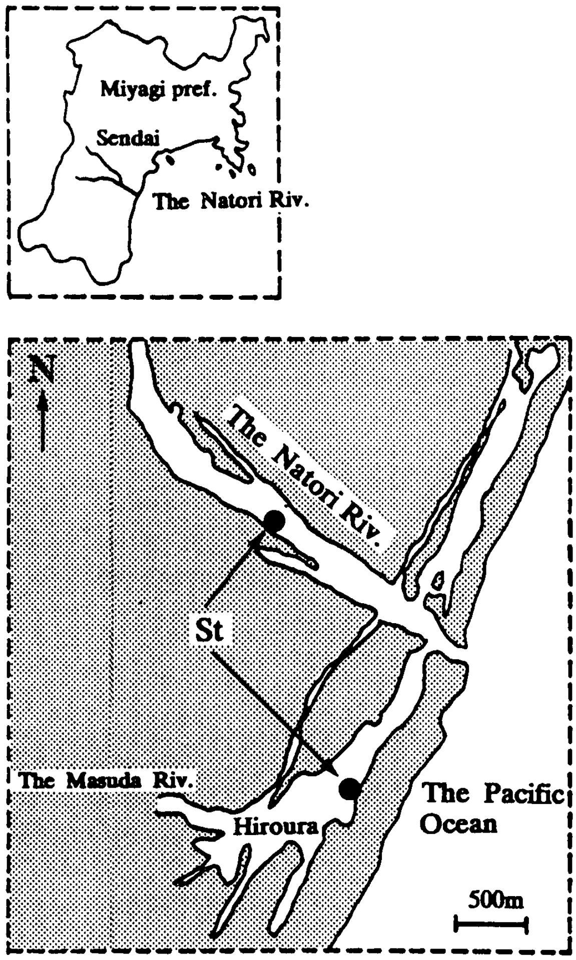

FIG. 1. Map showing the study area in the Natori River and the Hiroura.

Biological survey

The observations on the feeding, excreting, burrowing behavior and movements of the animals were undertaken precisely in whole tidal flat for 24 hours. Benthic animal samples were collected by the quadrat method, $25 \times 25 \times 15$ cm, and they were fixed with 10% formalin. The samples sorted by use of the sieve with 1 mm-mesh were analyzed for species composition, size distribution and stomach contents.

In order to know the characteristics of the feces of each species, the animals caught in the tidal flat were brought to the laboratory and their feces were observed.

The particulate matters of sediment used as food for benthic animals were observed under optical-microscope and scanning electron microscope.

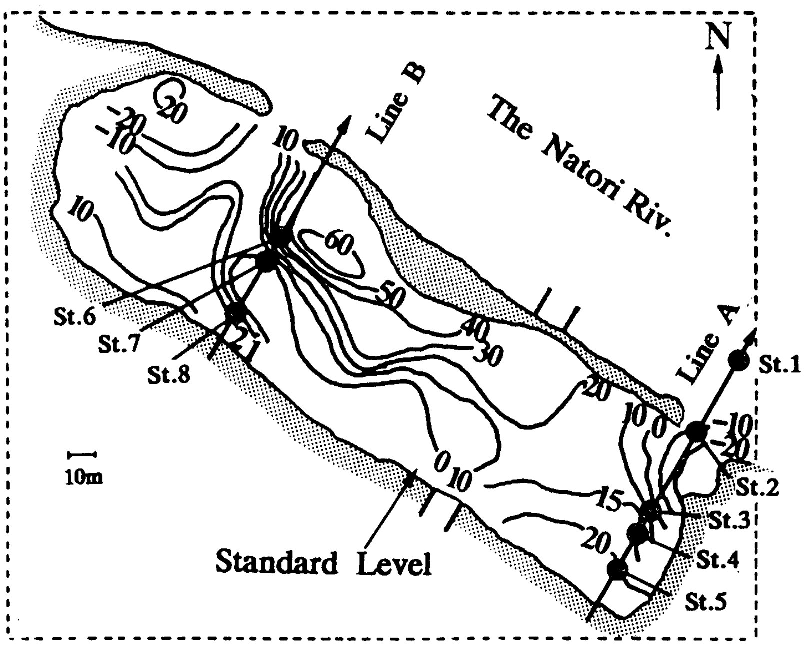

FIG. 2. Location of each station along Line A and Line B and the relative levels in cm on the tidal flat in the Natori River on 25 Aug. 1994.

Results

The characteristics of the water condition of the Natori River and the Hiroura and represented in Fig. 3. The seasonal change of temperature is similar both in the Natori River and in the Hiroura, but chlorophyll *a* in the Hiroura is higher than in the Natori River.

I. Specialization on micro-subsystem

Physical conditions of Bottom sediment

The relative levels at tidal flat in the Natori River on 25 Aug., 1994 are shown in Fig. 2. A little difference in the ups and downs with several meters scales are discovered. The maximum value of difference of the relative level between the highest site and the lowest site is about 1 m. The sediment conditions are regulated by a combination of water current and relative levels, because of the relative level effects exposure period and water current effects accumulation mechanism of sand.

The vertical profiles of the characteristics of sediments such as median size, silt-clay contents and moisture at each station are represented in Fig. 4.

In the center of river, St. 1, is usually covered with flowing water and the exposure period is less than 1 hr a day at ebb on Spring Tide. The median size of sediment is 0.8 mm (coarse sand) and the silt-clay content is low (0.2%) on the

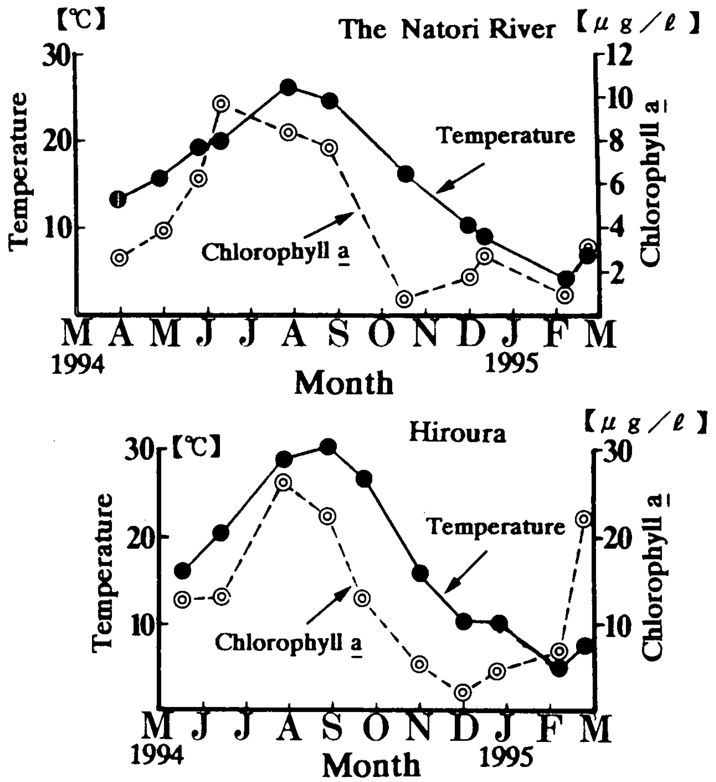

FIG. 3. Seasonal change of water temperature and chlorophyll *a* of water from 1994 to 1995 in the Natori River and the Hiroura.

surface. Silt-clay content is higher according to depth, but moisture and median size are identical at each depth.

In the highest level site, St. 6, the flat is exposed for about 7 hrs a day on Spring Tide. At this station, the moisture and silt-clay content are lower than other station, and the values 10% and 0.2% respectively.

At Sts. 3 and 4, intermediate zone between river and land, finer grain size (0.4 mm) and higher silt-clay content (10-20%), higher moisture (30%) are indicated in comparison with St. 1 and 2.

Near the land, St. 5, silt clay content (5%) and moisture are less than Sts. 3 and 4.

The recess and lower level site, St. 8, the flat is exposed for 4-5 hrs a day. The highest silt clay content (40%), the highest moisture (30-40%) and the finest median size (0.09 mm) are detected in all the stations.

These physical conditions of sediments may lead to functional difference as habitat for each species, and those may effect primary production and decomposition mechanisms of organic matter.

Particulate matter of sediment

On the tidal flat, we can find abundant benthic diatoms in the surface layer

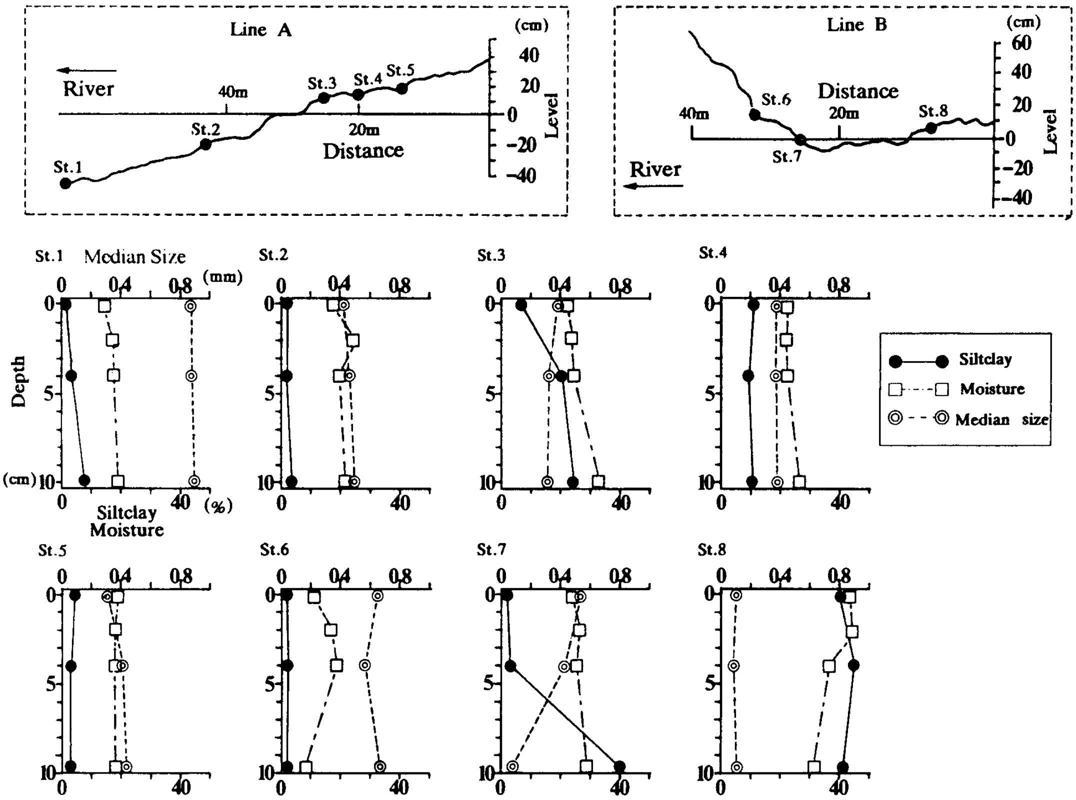

FIG. 4. Vertical profiles of sediment characteristics, median size, silt-clay content and moisture at each station on 14, Jane, 1994 in the Natori River. Upper Figures enclosed by broken lines show undulation along the line A and B.

1 cm from the bed, and they are utilized as main food for benthic animals such as crabs, other small crustaceans and bivalves. In the surface layer of the bed, several organic substances other than benthic diatoms are aggregating among the sediment so called detritus, are shown in Fig. 5.

The vertical distributions of sediment-chlorophyll *a* and COD in the layer of 10 cm from the surface are shown in Fig. 6. In this Figure, it is recognized that the concentrations of chlorophyll *a* are most high in the surface of the bed and drastically decrease in accordance with increment depth from the surface in all the stations.

On the other hand, COD slightly decrease in depth of 2-3 cm, in comparison with the surface, but in the depth of 10 cm, the values increase and attain to near values of the surface. The high value of COD means high production of benthic diatoms on the flat, however, concerning the phenomena in the depth of 10 cm, it may be thought that, the accumulation of organic matter other than living diatoms is high, and the velocity of decomposition of organic detritus is low in this layer.

FIG. 5. Scanning Electron Microscopic photograph of the typical particulate matter of sediment, benthic diatom (*Diploneis splendica* attached with bacteria) and detritus.

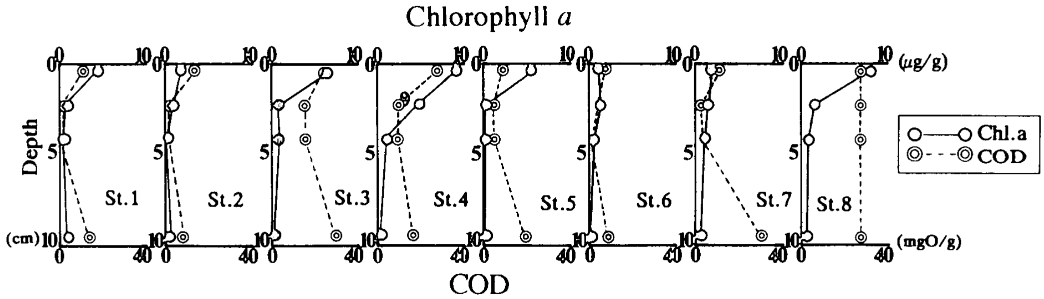

FIG. 6. Vertical profiles of sediment chlorophyll *a* and COD at each station observed on 14, June, 1994 in the Natori River.

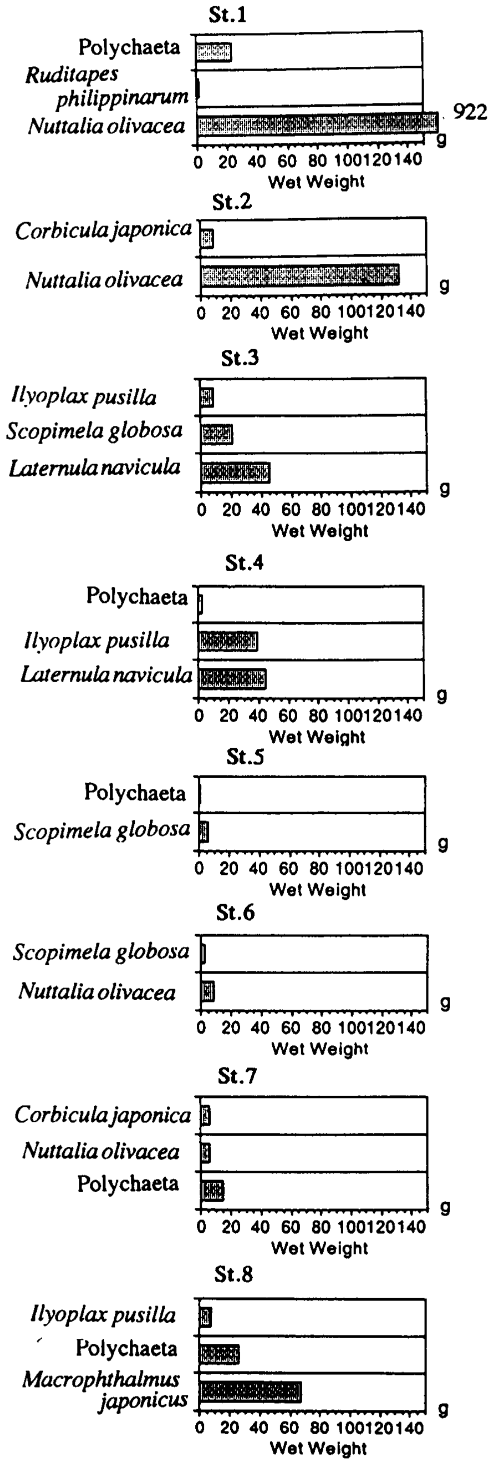

FIG. 7. Standing crops of benthic animals (g/m^2) at each station on 14, June, 1994 in the Natori River.

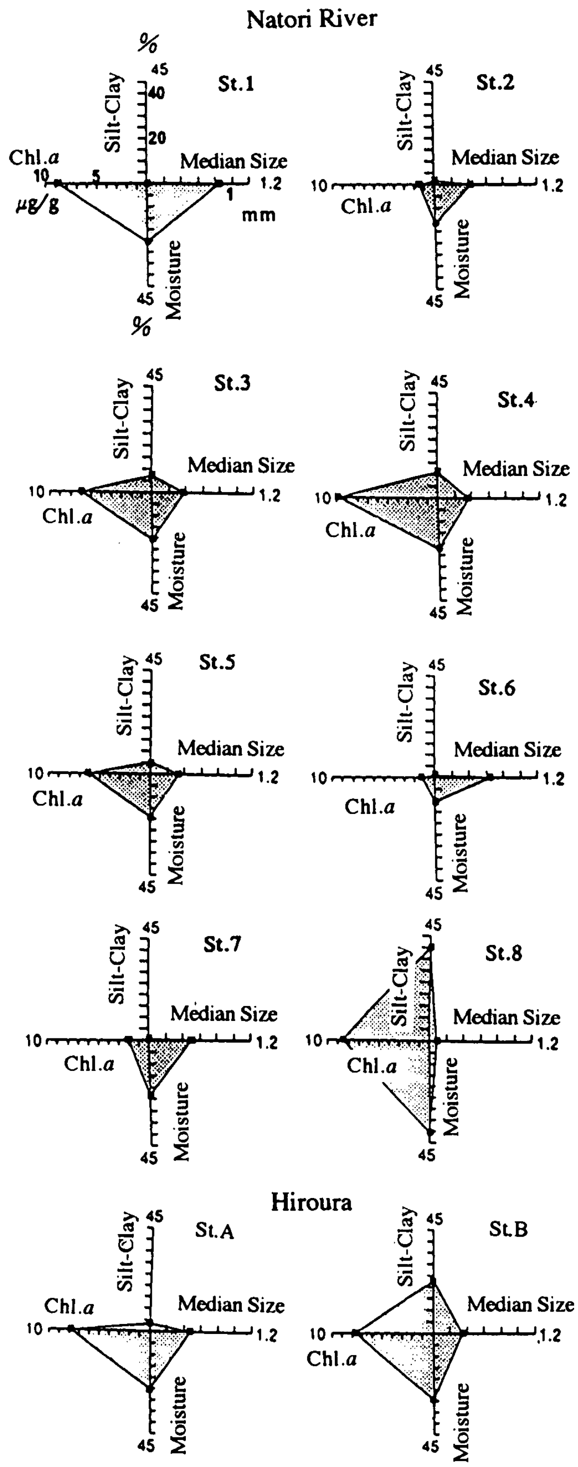

FIG. 8. Radar charts of sediment characteristics, median size, silt-clay content, moisture and sediment chlorophyll *a* at each station obtained in the Natori River on 14, June 1994, and in the Hiroura on 19 April 1995.

Benthic animals and Combination of environmental factors

The list of standing crop of benthic animals (g/m^2) at the tidal flat in the Natori River on 14 June 1994 is shown in Fig. 7. Different Species compositions in each site can be indicated specific selectivity for habitat by each species.

Considerable combinations of important environmental elements for benthic animals were represented on radar charts in Fig. 8. This is a concise diagram for the explanation of the characteristics of sediments. Concerning regulation on burrowing behavior and neat building, the hardness of the sediment may be one of the important factors. The hardness of the sediment will be determined by combination of 3 factors, grain size, silt-clay and moisture.

Silt-clay content may affect ingestion rate of food for bivalves, too. For example, under the higher silt-clay condition on the laboratory experiments with *Ruditapes philippinarum* and *Corbicula japonica*, a plenty of pseudo-feces and lower growth rates are observed. These facts suggest that silt clay content of sediments are affecting not only function for habitat but also feeding efficiency (2).

Chlorophyll *a* contents of sediments surface is considered as an important factor of food supply. We can recognize the typical shape of each habitat by a combination of these sediment factors as follows.

Nuttalia olivacea selects the following conditions; high moisture (20-30%) and low silt-clay (less than 5%) and high chlorophyll *a* (about 8 μg/g) such as St. 1.

Laternula navicula prefers higher silt and moisture sediment and finer sand (Sts. 3 and 4.) compared with *Nuttalia olivacea.*

Seeing the habitat of two small crabs, *Ilyoplax pusilla* and *Scopimela globosa.* They are neighboring each other. *Ilyoplax pusilla* prefers wet and muddy sand (St. 4), on the other hand, *Scopimela globosa* selects lower moisture and fine sand such as Sts. 5 and 6.

The habitat of *Macrophthlmus japonicus*, a kind of a large crab in ocypodit crab, is characterized by the highest silt-clay (40%), moisture (40%) and the finest median size (0.09 mm) such as St. 8.

These phenomena, reveals that each species selects species specific sediment conditions for habitat.

By the way, these specializations micro-subsystem are discovered at other subsystem, Hiroura. The biomass of *Nuttalia olivacrea* in St. A is about 20 times that of St. B, nevertheless those distance are only 50 cm. In the case of 19 April 1995, the biomass of *Nuttalia olivacea*, at St. A and St. B is 1087 g/m^2 and 52.8 g/m^2, respectively. As shown in Fig. 8, clear differences in sediment types are recognized among these stations.

The size distribution of *N. olivacea* at each depth at St. A is shown in Fig. 9,

TABLE 1. *Showing a list of the animals caught in the tidal flat and the items found in their stomach, their feces, and feeding time observed in the tidal flat in Natori River from May to July 1994.*

Species	Stomach contents	Feces	Feeding Time
Fish			
Kareius bicoloratus	Polychaeta Copepoda	Copepoda	Covered with water
Acanthogobius lacticeps	*Laternula navicula* Feces	Benthic diatom	Covered with water
Crab			
Helice trindes trindes trindes	Benthic Diatom nematoda	Benthic Diatom	Covered with water
Macrophthalmus japonicus	Benthic Diatom Detritus	Benthic Diatom	Exposure
Scopimela globosa	Benthic Diatom Detritus	Benthic Diatom	Exposure
Ilyoplax pusilla	Benthic Diatom Detritus	Benthic Diatom	Exposure
Hemigrapsus longitarsis	Benthic Diatom Detritus	Benthic Diatom	Covered with water
Bivalve			
Nuttalia olivacea	Benthic Diatom Detritus	Benthic Diatom	Covered with water
Laternula navicula	Benthic Diatom Detritus	Benthic Diatom	Covered with water
Corbicula japonica	Benthic Diatom Phytoplankton Detritus	Benthic Diatom Phytoplankton	Covered with water
Ruditapes philippinarum	Bentic Diatom Phytoplankton Detritus	Benthic Diatom Phytoplankton	Covered with water
Polychaeta	Benthic Diatom Detritus	Benthic Diatom	Covered with water

which indicates vertical separation of habitat in juvenile and adult. From this Figure, it is obvious that *N. olivacea* is going to select a deeper site accordinsg to their growth. Such distribution of pattern of the species are usually observed.

These facts indicate that each species selects moderate environmental conditions and secures habitat each appropriate growth stage.

II. Continuity among micro subsystems

The data obtained by the field observation on the trophic life of animals in tidal flats are shown in Table 1. It is recognized that benthic diatom and detrius are important food substances for benthic animals in the estuary system. On the

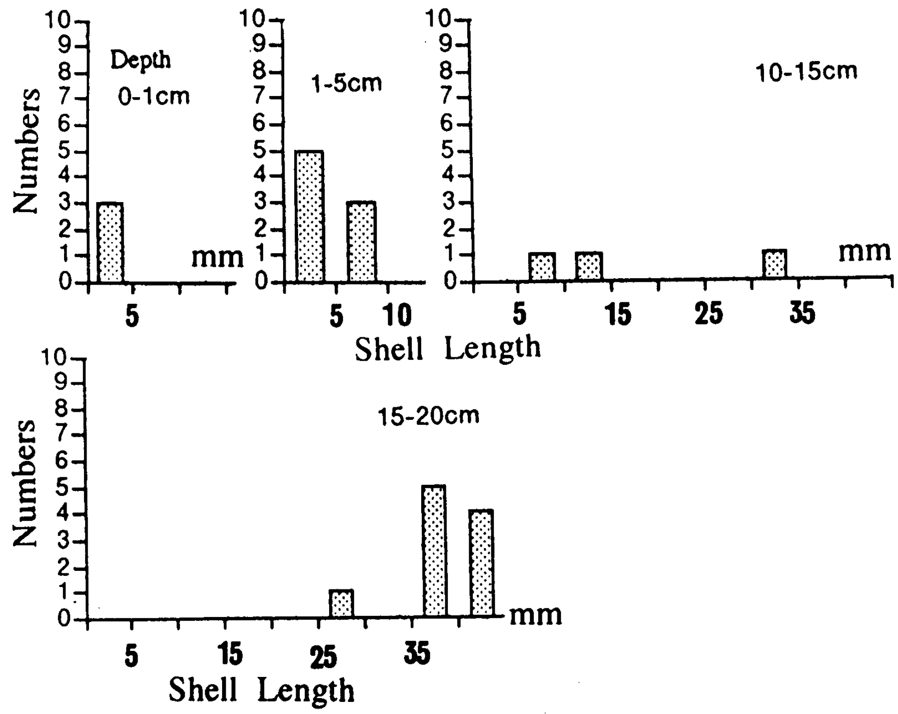

FIG. 9. Size distribution of *Nuttalia olivacea* in each depth from the surface of the bed on 19 April 1995 at St. A in the Hiroura.

tidal flat, we can observe that the large crab such as *Helice trindes trindes trindes* are grazing the benthic diatoms and excreting around various sites in the tidal flat. And the feces are decomposed by bacteria and transferred into other site by the water. Besides, we can observe that the feces are directly utilized for food by fish such as *Acanthogobius lacticips*. These facts are examples of a proof that specialized micro-subsystems have functional linkage through the circulation of nutritional materials.

Discussion

The conceptual diagram of the present study is shown in Fig. 10. Geological and spatial specificity on the biological production structures are found in ocean ecosystem. These systems are consisted of functional relationships between abiotic environmental elements and biotic communities. Various scales of subsystems can be set up according to the view point of the researcher who wants to know the structure of ecosystem.

In this study, we set up the micro-subsystems, based on the differences in scenery of the tidal flats and in the color or hardness of sediments. The width and length of the tidal flats are 80×100 m (in the Natori River) and $100 \times 1{,}000$

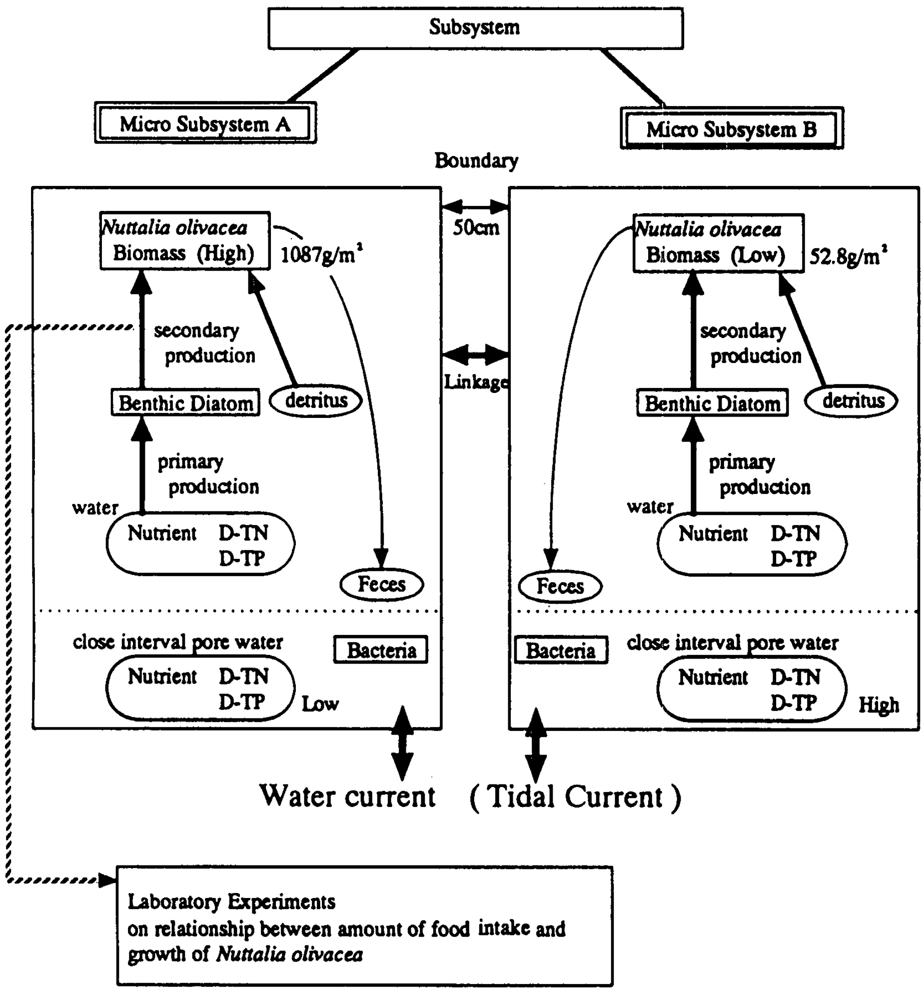

FIG. 10. Conceptual diagram of the present study on coupling mechanisms between neighboring micro-subsystems. Model sites are Sts A and B in the Hiroura.
Biomass data of *Nuttalia olivacea* show the value observed on 19 April 1995.

m (in the Hiroura) respectively, and spatial scale of the micro subsystems is less than 1 m. In the latter tidal flat, we set up two model sites, micro-subsystems A and B. We chose *N. olivacea* as a model species of the secondary producer and benthic diatoms as a primary producer, and the study is in progress. Concerning the micro subsystem A, it is found that the distribution of *Nuttalia ovivacea* is abundant and the silt content is low ; however, in the neighboring micro subsystem B, only 50 cm apart from A. There, we can find that the abundance of *Nuttalia olivacea* is lower and grain size of sand is finer than in micro-sybsysem A is shown in Fig. 8.

The difference between micro-subsystems A and B may be determined by the differences of the velocity on biological production, decomposition of organic matter, accumulation and nutrient transport in those micro-subsystems.

In the present investigation, it is clear that such differences or specialization on each micro-subsystem are almost stable.

Such phenomena suggest the existence of equilibrium on the flow of nutritional substances between micro-subsystems A and B. The equilibrium is sustained by the periodic current, and primary production of algae and animal activity such as feeding and excreting.

In the course of the study, we must promote several experimental surveys on the circulation of nutritional substances, food consumption, growth and excretion of the secondary producers. These animal activities may lead to the linkage among micro-subsystems with the cooperation of a water current such as a tidal current. In this way, continuity of the different subsystems and the equilibrium in the tidal flats are maintained.

Consequently, in the study on coupling mechanism among micro-subsystem, it is necessary to make clear the variation of the flow velocity of nutritional substances by the tidal current, and the characteristics of biological production and the decomposition by bacteria in each subsystem.

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